The Response of Red Pine (*Pinus resinosa* Ait.) Seedlings To Growth in Unburned and Burned Soil

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A

Major Report

submitted

by

William A. Patterson, III

in

fulfillment

of

the requirements

of

For 200

on

1 October 1969

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INTRODUCTION

Fire has, traditionally, been considered a major enemy to forested areas. Only in the past forty to fifty years has its use as a silvicultural tool been advocated. In 1916, J. W. Toumey stated before the Southern Forestry Congress that "Fire, more than anything else appears to be the silvicultural tool which is to determine the future stands" (Schiff, 1960). Because of the tremendous destruction that uncontrolled fire can cause, however, his prediction has gained acceptance slowly. For many years, the U. S. Forest Service argued for the exclusion of burning from all forested lands. An effective system for fire prevention and control resulted from the early and intensive efforts to eradicate forest fires. While this is, of course, desireable, the attitude of some foresters has severely hampered research into the use of controlled burning.

Associated with the slow acceptance (except in the southern pine region) of controlled burning has been a lack of research concerning the ecological effects of fire. Most fire ecology studies have taken place only in the last twenty to twenty-five years. Ahlgren and Ahlgren (1960) presented an extensive review of the ecological effects of forest fires. More recent studies have added information. A review of literature on the effects of fire on soil chemical properties is found in the paper attached as an appendix to this report.

While many of the effects of burning on soil chemical properties have been identified, effects on subsequent vegetative growth are less well understood. It has been established that fire, through the destruction of litter layers and the exposure of mineral soil, aids in the germination and establishment of the three major pine species (*Pinus banksiana* Lamb., *Pinus resinosa* Ait., and *Pinus strobus* L.) of northeastern and north central regions of the United States (Maisurow, 1935; Horton and Bedell, 1960; and Ahlgren, 1959, 1960). Few studies have, however, examined the effects of fire related changes in soil chemical properties on vegetative growth. Ahlgren (1960) determined for oats (*Avena sativa* L.) and sunflower (*Helianthus annus* L.) the biological yield capacity of soil from burned and unburned areas. He reported dry weight increases of generally greater than twenty percent for plants grown in burned soil compared to those grown in unburned soil (upper eight inches thoroughly mixed). No statistical verification of his data was provided nor was chemical analysis of the plant material reported. Furthermore, Ahlgren used annual herbaceous species which are not found in Forest communities.

Because of the apparent lack of information concerning the effects of burning on the growth of forest tree species seedlings, a study was conducted to determine the growth response and nutrient uptake of red pine planted in burned and unburned soil.

STUDY AREA

Seedlings were grown under green house conditions. Prior to the planting of seeds it was necessary to locate a forested area which had recently been burned and from which soil samples could be collected. Conversations in July 1967 with Mr. Vern Miller, Minnesota Conservation Department forester located at Itasca State Park, indicated that such an area existed nearby. It is approximately one and one-half miles east of Mitchel Lake in Hubbard County, Minnesota (SW$\frac{1}{4}$,NW$\frac{1}{4}$, Sec. 9, T.143N., R.36W.). The topography is gently rolling. The soil, formed from glacial till, is a Marquette loamy sand, is well drained, and contains a gravel layer of varying thickness at a depth ranging from one to two feet.

The pre-fire vegetation on the area consisted of an overstory of sixty to seventy year old red, white, and jack pine with patches of aspen (*Populus tremuloides* Michx.) and white birch (*Betula papyrifera* Marsh.). An extensive understory was dominated by hazel (*Corylus cornuta* Marsh.). A portion of the area was logged during the winter of 1966-1967, and in early June 1967 a wild fire burned approximately seven acres. Soil samples were taken from a spot which had been burned and logged and a nearby area which had been neither burned nor logged. Because slash was present on the burned area, the fire was relatively hot and killed most of the pines which had been left in the overstory. The litter was reduced to ash and mineral soil was exposed in places.

PROCEDURE

Soils were sampled at both the burned and unburned sites two and a half months after the fire. The upper four inches of soil were sieved to pass a one-quarter inch screen. Subsamples were taken for chemical analysis, and the remaining soil was used to fill $4\frac{1}{2}$" by $4\frac{1}{2}$" by 6" deep plastic pots. Six pots each were filled for the treatment (burn) and control.

Fifteen red pine seeds were planted in each pot. The seed lot (with all seeds from the same seed source) was tested for viability, and seeds were treated with the fungicide captan prior to planting. They were covered with one-eighth to one-fourth inch of soil, and seventy milliliters of distilled water were applied to the surface of each pot twice weekly. This planting and watering procedure approximates that described by Benzie (1965).

All seedlings that were to germinate did so within three to four weeks, and they were then grown under constant temperature (71° F.) and light (eighteen hour photoperiod) conditions. After seven months growth all seedlings were harvested. For each seedling stem height (soil-stem interface to the tip of the terminal bud) was recorded. Seedlings were oven dried at 103° C. for twenty-four hours, and dry weight was determined. All needles which were green at the time of harvest were removed from the seedlings and collectively (by pot) ground in a Willey mill (with a twenty mesh stainless steel screen). This yielded twelve samples of ground material. One gram from each sample was ashed for four hours at 525° C. and placed in solution with 5 ml. of 0.5 percent lithium and 15 percent hydrochloric acid in distilled water. This solution was analysed for phosphorus, potassium, calcium, strontium, iron, magnesium, zinc, copper, molybdenum, manganese, and boron with a Jarrell-Ash emission spectrograph. One hundred milligrams of each sample were analysed for nitrogen by standard micro-Kjeldahl technique.

DISCUSSION AND RESULTS

A complete discussion of the soils analysis is found in the attached report. In general, it would appear that burning resulted in changes in soil chemical properties which would favor increased growth.

A viability test of 100 seeds from the lot used in this study showed 100 percent germination. Examination of Appendix A indicates that not all seeds germinated in the pots. More than 93 percent of all seeds did germinate, however, and there was virtually no difference between treatments. Pots were to have been thinned so that each pot had the same density of seedlings, but unforseen military commitments prevented the author from doing this at the proper time, and it was necessary to leave the pots as they were. Because the number of seedlings varied from 13 to 15 per pot, statistical testing of the data required an analysis of covariance to separate the density effect from treatment effects. The method used is that described in Snedecor and Cochran (1967) p. 433.

The average height and weight of individual trees is recorded (by pot) in Appendix A. Treatment averages and the statistical significance of any differences between treatments are presented in Table 1. The table indicates that trees grown on burned soil exhibit increased height growth and dry matter production although only the increase in weight is statistically significant. The average increase in height growth was only 2.8 percent, but dry matter production was increased by 11.1 percent. This is a fairly substantial increase considering the short period of time the seedlings were grown.

Given that red pine exhibits increased dry matter production on burned soil, the question of whether or not increases in nutrient uptake also occur remains unanswered. With increased biological activity, it would seem logical that nutrient uptake would also increase. If this is so, do all nutrients show increases and can

	Treatment		Test for Slope	Test for Difference in Means
	No Burn	Burn	(F with 1 and 8 d.f.)	(F with 1 and 9 d.f.)
Height (cm.)	4.97	5.11	0.42	1.97
Dry wt. (gm.)	0.1451	0.1617	0.01	3.93*

* p.α=0.1

Table 1. Treatment means for height and weight of red pine seedlings grown in burned and unburned soil with F values for analysis of covariance.

	Treatment		Test for Slope	Test for Difference in Means
Element	No Burn	Burn	(F with 1 and 8 d.f.)	(F with 1 and 9 d.f.)
P (%)	0.188	0.120	0.52	0.28
K (%)	0.490	0.711	0.29	24.81*****
Ca (%)	0.336	0.462	0.33	18.15*****
Sr (ppm)	5.857	10.891	0.04	27.67*****
Fe (ppm)	95.925	104.657	0.03	0.22
Mg (%)	0.147	0.153	0.57	0.53
Zn (ppm)	79.070	70.093	0.82	2.31
Cu (ppm)	11.969	10.728	0.08	0.03
Mo (ppm)	0.432	0.453	3.64*	0.65
Mn (ppm)	241.091	256.579	0.89	0.60
Br (ppm)	14.494	21.345	0.07	19.30*****
			(F with 1 and 7 d.f.)	(F with 1 and 8 d.f.)
N (%)	1.919	2.214	0.62	7.97

* p.α=0.1
*** p.α=0..25
***** p.α=0.005

Table 2. Treatment means for nutrient concentrations in needles from red pine seedlings grown in burned and unburned soil with F values for analysis of covariance.

they be related to increases in soil concentrations of the same elements? To answer these questions, nutrient analysis of the needles from each pot was conducted. Nutrient values are presented by pot in Appendix B, while treatment means and the statistical differences between means are presented in Table 2.

Among the plant macronutrients tested, significant increases in concentration levels related to burning occurred for potassium, calcium, and nitrogen. The increases in potassium (45 percent) and calcium (38 percent) are greater than those shown in the soil analysis (37 and 25 percent respectively), while the increase in foliar nitrogen concentration is less than in the soil (17 versus 25 percent). Concentrations of foliar phosphorus and magnesium were only slightly (and non-significantly) increased in the seedlings grown on burned soil. Soil analysis shows that burning had little effect on magnesium concentrations, and the results of the foliar analysis are not unexpected. Soil phosphorus levels, on the other hand, increased one and a half fold, and it is difficult to explain why an increase is not also found in the needles. The soil chemistry of phosphorus is complex, but several explanations are possible. First, soluble phosphorus is readily bound in mineral soil (Taylor, 1967). It is possible that the phosphorus released by burning was unavailable to plant uptake even though the hydrogen ion concentration gradient used in leaching the soil was capable of removing some of it.

Another possible explanation involves the increase noted in calcium concentrations in the soil. Excessive amounts of soil calcium may block uptake of phosphorus by plants (Buckman and Brady, 1965). This explanation is tenuous, however, since boron is also affected by high calcium levels, and the seedlings grown in burned soil show a significantly greater amount of this element.

Other than for boron there was no significant increase in the uptake of micronutrients by plants grown on burned soil. Iron and manganese showed slight increases and zinc and copper slight decreases for the burned compared to the unburned treatment. The test for slope showed a significant F value for molybdenum indicating density is not a factor in the uptake of this element. Thus the test for difference between means is invalidated. Concentrations of the element strontium were found to be significantly greater in the foliage of plants grown in burned soil. The increase is probably directly related to the increase in productivity.

The increased weight and nitrogen concentrations of the plants grown in burned soil appear to at least partially answer the questions posed in the attached soils report. Even if there is a net loss of nitrogen from an ecosystem that has been burned, plant growth is at least temporarily increased as a result of increased soil concentrations of the element.

CONCLUSION

Red pine seedlings grown in burned soil show significant increases in dry matter production and concentrations of nitrogen, potassium, calcium, boron, and strontium when compared with seedlings grown in unburned soil. Nonsignificant increases in heigth growth and concentrations of foliar phosphorus, iron, magnesium, molybdenum, and manganese were observed. Zinc and copper concentrations in seedlings grown in burned soil decreased but not significantly. It would appear that the release of nutrients by fire's combustion of litter and above ground biomass is beneficial to the growth of red pine, at least in the early stages of its development. This study was not designed to determine how long increased growth and nutrient uptake persist.
It is possible that early growth is stimulated by increased soil concentrations while later development is retarded by the net loss of certain elements (e.g. nitrogen). Ahlgren (1960) has reported, however, that no decrease in soil nutrient levels could be noted five years after a prescribed burn in northeastern Minnesota. This would indicate that a single fire does not result in an appreciable reduction in soil fertility.
This study was conducted using "mixed" soil and carefully controlled light, heat, and moisture conditions. It's results, therefore, are not directly applicable to field conditions.

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APPENDIX A

Height and Weight of Red Pine Seedlings Grown in Burned and Unburned Soil

No Burn

Pot #1

Tree No.	Height (cm.)	Weight (gm.)
1	4.80	0.1164
2	5.20	0.1148
3	4.85	0.1138
4	3.50	0.0536
5	4.95	0.1338
6	4.70	0.1179
7	5.20	0.0980
8	3.15	0.0675
9	5.00	0.1449
10	5.30	0.1469
11	5.05	0.0977
12	5.30	0.1447
13	6.00	0.1096
14	5.50	0.1604
15	4.90	0.1295
Mean	4.89	0.1184

Pot #2

Tree No.	Height (cm.)	Weight (gm.)
1	4.95	0.2156
2	4.10	0.1120
3	3.65	0.1236
4	5.50	0.1537
5	5.65	0.2167
6	4.55	0.2511
7	4.60	0.1198
8	4.80	0.1871
9	3.70	0.0890
10	5.15	0.2170
11	4.35	0.1256
12	5.25	0.1674
13	3.70	0.1049
	4.61	0.1603

Pot #3

Tree No.	Height (cm.)	Weight (gm.)
1	4.90	0.1070
2	5.40	0.1311
3	5.90	0.1628
4	5.80	0.1633
5	6.45	0.3085
6	6.50	0.2717
7	4.55	0.0774
8	3.60	0.0499
9	5.50	0.1759
10	6.75	0.3860
11	5.35	0.1478
12	3.85	0.0786
13	6.30	0.2438
14	dead	
	5.45	0.1696

Pot #4

Tree No.	Height (cm.)	Weight (gm.)
1	4.30	0.0306
2	3.45	0.0493
3	6.00	0.1840
4	4.40	0.1370
5	5.85	0.2170
6	5.75	0.1164
7	5.25	0.1211
8	5.20	0.1492
9	4.90	0.1741
10	5.50	0.1453
11	5.80	0.2121
12	2.60	0.0312
13	3.60	0.0837
14	3.55	0.0961
15	dead	
Mean	4.73	0.1248

Pot #5

Tree No.	Height (cm.)	Weight (gm.)
1	5.15	0.1671
2	5.60	0.1522
3	5.00	0.1566
4	5.00	0.1477
5	5.25	0.1196
6	5.05	0.1486
7	4.25	0.1110
8	5.55	0.1922
9	5.70	0.1285
10	4.40	0.2218
11	5.30	0.1991
12	4.90	0.0927
13	3.65	0.0517
14	4.20	0.0551
	4.93	0.1389

Pot #6

Tree No.	Height (cm.)	Weight (gm.)
1	3.20	0.0447
2	5.60	0.2746
3	4.15	0.0851
4	5.40	0.1549
5	3.55	0.0749
6	5.50	0.1308
7	4.70	0.1022
8	3.90	0.0924
9	5.95	0.2521
10	6.10	0.2492
11	6.70	0.1648
12	5.40	0.1220
13	6.60	0.3111
	5.13	0.1584

Burn

Pot #1

Tree No.	Height (cm.)	Weight (gm.)
1	5.20	0.1737
2	4.75	0.1245
3	5.10	0.1109
4	5.85	0.1916
5	5.00	0.2120
6	5.15	0.1916
7	5.20	0.1412
8	5.20	0.1183
9	4.80	0.1070
10	4.00	0.1723
11	5.15	0.1613
12	4.30	0.1164
13	5.20	0.1809
14	4.05	0.0795
Mean	4.93	0.1487

Pot #2

Tree No.	Height (cm.)	Weight (gm.)
1	5.80	0.1169
2	5.30	0.2688
3	7.20	0.5600
4	7.70	0.4009
5	5.70	0.1768
6	5.30	0.2187
7	7.05	0.3212
8	6.35	0.2373
9	5.85	0.3146
10	5.00	0.0853
11	5.90	0.1412
12	4.00	0.0683
13	3.60	0.0429
	5.75	0.2271

Pot #3

Tree No.	Height (cm.)	Weight (gm.)
1	4.45	0.1428
2	5.10	0.1738
3	4.95	0.1193
4	4.90	0.1689
5	4.10	0.1298
6	4.70	0.1379
7	3.10	0.0645
8	5.20	0.1776
9	5.20	0.1411
10	4.60	0.0851
11	5.30	0.1772
12	5.75	0.1324
13	5.50	0.1696
14	5.40	0.1478
	4.87	0.1406

Pot #4

Tree No.	Height (cm.)	Weight (gm.)
1	6.00	0.2613
2	4.45	0.1491
3	3.40	0.0402
4	6.20	0.1756
5	5.20	0.1114
6	4.40	0.1295
7	5.80	0.1974
8	3.70	0.0753
9	4.90	0.1526
10	4.90	0.1219
11	5.45	0.1484
12	4.75	0.3581
13	5.40	0.2257
14	4.65	0.1432
15	5.50	0.1947
Mean	4.98	0.1651

Pot #5

Tree No.	Height (cm.)	Weight (gm.)
1	5.55	0.2162
2	4.60	0.1256
3	5.50	0.1513
4	5.20	0.1730
5	5.95	0.2014
6	4.75	0.1624
7	4.95	0.1593
8	5.90	0.1732
9	5.20	0.1417
10	5.20	0.1139
11	5.10	0.1173
12	4.30	0.1240
13	3.20	0.0538
14	5.00	0.1268
15	6.30	0.3680
	5.11	0.1605

Pot #6

Tree No.	Height (cm.)	Weight (gm.)
1	4.80	0.1314
2	5.80	0.1413
3	5.65	0.1471
4	4.25	0.0878
5	3.55	0.0640
6	2.50	0.0267
7	5.00	0.1250
8	5.15	0.0914
9	5.90	0.1795
10	5.85	0.2385
11	6.70	0.2406
12	4.75	0.0857
13	5.60	0.1090
14	4.90	0.1273
	5.03	0.1282

APPENDIX B

Element Concentrations in Needles from Red Pine Seedlings Grown in Burned and Unburned Soils.

No Burn

Element		Pot #1	Pot #2	Pot #3	Pot #4	Pot #5	Pot #6
Phosphorus	*	0.190	0.188	0.153	0.183	0.182	0.207
Potassium	*	0.471	0.517	0.525	0.471	0.477	0.447
Calcium	*	0.334	0.377	0.374	0.324	0.304	0.303
Strontium	**	5.199	6.797	6.938	5.481	5.622	5.105
Iron	**	106.692	93.931	85.305	88.179	98.045	103.397
Magnesium	*	0.151	0.146	0.143	0.156	0.140	0.144
Zinc	**	84.762	72.328	67.275	80.360	82.637	87.061
Copper	**	8.262	12.267	15.237	12.847	12.433	10.771
Molybdenum	**	0.503	0.466	0.466	0.335	0.428	0.391
Manganese	**	266.096	263.274	213.798	258.642	223.390	221.346
Boron	**	15.075	13.682	14.646	14.111	15.128	14.325
Nitrogen	*	1.945	2.200	1.920	1.930	1.630	1.890

Burn

Element		Pot #1	Pot #2	Pot #3	Pot #4	Pot #5	Pot #6
Phosphorus	*	0.220	0.183	0.301	0.164	0.169	0.163
Potassium	*	0.588	0.801	0.871	0.621	0.732	0.651
Calcium	*	0.404	0.474	0.498	0.378	0.444	0.573
Strontium	**	9.099	10.885	11.071	8.676	10.602	15.013
Iron	**	98.045	72.190	117.426	106.694	73.828	159.761
Magnesium	*	0.138	0.144	0.185	0.141	0.137	0.175
Zinc	**	70.583	66.335	93.022	66.804	67.676	62.140
Copper	**	4.374	4.969	23.972	7.844	6.830	16.384
Molybdenum	**	0.428	0.559	0.597	0.317	0.419	0.410
Manganese	**	270.906	233.722	302.496	225.945	248.066	258.326
Boron	**	23.598	17.694	26.667	18.705	19.932	21.475
Nitrogen	*	2.240	2.040	2.180	2.390	2.220	m

m= missing
*= %
**= ppm

Results of Leaching Burned and Unburned Soils
(Key Words: Leaching, Forest Soils, Organic Matter)

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Submitted

by

William A. Patterson, III

in

partial fulfillment

of

the requirements

of

Soil 135

on

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TABLES AND FIGURES

ABSTRACT

Two soils, one from an area which had been burned and one from an unburned area, were leached with a solution designed to give a hydrogen ion concentration gradient. Fractions were collected from the effluent and the following analyses conducted: hydrogen ion concentration, percent organic matter, and nutrient concentration. With both soils, organic matter concentration increased as leaching progressed, but generally greater values were obtained for fractions collected from the burned soil. The greatest amount of nutrients from the unburned soil was in the first fractions. However, from the burned soil the last fractions contained the greatest amounts of nutrients and the total amount of individual nutrients was generally greater for this soil. In both soils (and with few exceptions) the amounts of nutrient were high in the first fractions collected followed by a gradual decrease and then, in later fractions, another increase. Although titration failed to illustrate a hydrogen ion concentration gradient, patterns of organic matter and nutrient release indicate that gradients did exist but were masked by the high buffering capacity of the leaching solution.

LITERATURE REVIEW

During the past 20 to 25 years there have been a great number of studies conducted to determine the effects of fire upon the chemical and physical properties of soils. It is not the purpose of this paper to review all the literature on the subject as such a review is already available (Ahlgren and Ahlgren, 1960). Fire appears to affect certain changes in soil chemical properties and a few generalizations may be made, however. Ahlgren and Ahlgren (1960) note that burning decreases both soil acidity and buffering capacity. They found these changes to be modified after a year. Zwolenski (1967) has reported increases in pH, percent carbon, and percent total nitrogen for the top 2" of soil following fire. Scotter (1963) found fire to increase available phosphorus and exchangeable calcium. Ahlgren (1963) substantiates these findings and adds magnesium to the list of nutrients increased by burning. He states that potassium is increased by fire but is subject to rapid leaching. The effect of burning upon nitrogen concentrations is rather complicated as this important plant macronutrient is subject to volatilization at high temperatures. Several studies have reported increases in nitrogen levels following fire and Ahlgren and Ahlgren (1960) cite increased nitrification by soil microorganisms as a possible cause. Knight (1966), however, has presented contradictory data. He reports that the laboratory burning of the L, F, and H layers of <u>Tsuga heterophylla</u>/<u>Pseudotsuga taxifolia</u> litter results in a 25 to 64 percent decrease in nitrogen at temperatures between 300° and 700° C. (No losses were observed with burning below 300° C.) Although he reported concentrations of nitrogen in residual matter to be increased (which would substantiate other reports), he found high temperature burning to appreciably reduce the total amount of nitrogen on the forest floor.

There has been little work on the effects of burning upon micronutrients.

OBJECTIVES

Despite the above generalizations, variations do occur depending upon the intensity of the burn, the material burned, and the type of soil upon which the fire occurs. To the forester who is faced with the problem of wild fire and the apparent silvicultural desireability of controlled burning, an understanding of the effects of fire upon soil are important. Of particular interest are the effects of changes in soil chemical properties upon the growth of seedlings planted in an effort to reforest burned areas. The following is a report of chemical analysis conducted on burned and unburned soils and is part of a broader study to determine the reactions of red pine (*Pinus resinosa* Ait.) seedlings to growth in these soils. The purpose of this paper, then, is to report the quantitative results of soil chemical analysis as well as qualitative effectiveness of the experimental procedure.

PROCEDURE

Soil samples were collected from an area which had been burned and from a similar area close by which had not been burned. The areas, covered by 50 to 60 year old red pine prior to the fire, are near Lake Itasca, Minnesota. One of the areas was burned in early

June, 1967 and samples were taken in late August of the same year. Soils were sifted through a 2 mm. sieve and pH determinations were made using a Beckman zeromatic pH meter. Ten grams of soil mixed with 10 ml. of distilled water were allowed to stand 10 minutes before readings were taken. Percent total nitrogen determinations were arrived at using standard micro-Kjeldahl procedure.

One hundred grams of soil were then placed in a column with a stopcock attached to the base. Glass wool was positioned at the top and the bottom of the column. An arrangement was devised above the column to supply a leaching solution which would have a hydrogen ion gradient. Two hundred and fifty milliliters of ammonium acetate adjusted to 0.1 normality were placed in a container. As one drop flowed from it, a drop of 0.1 normal hydrochloric acid flowed into it from a container filled with 250 ml. of the acid. The solution flowed through the column and as each drop left the column, it was collected and counted by an automatic fraction collector (see Figure 1).

Five milliliter fractions were collected with leaching being discontinued when 250 ml. had passed into the soil column. One column of each soil was leached. Fractions collected from each sample were prepeared for analysis in the following manner, Twenty milliliters, four consecutive fractions, were readied for emission spectrograph analysis by placing them in a beaker, evaporating dry, and bringing back into solution with 2 ml. of 0.5 percent lithium and 15 percent hydrochloric acid solution. The next 5 ml. fraction was removed and titrated with 0.1 normal sodium hydroxide. Four fractions were again removed and prepared for emission spectrograph analysis. Then 5 ml. were taken and organic matter determined by

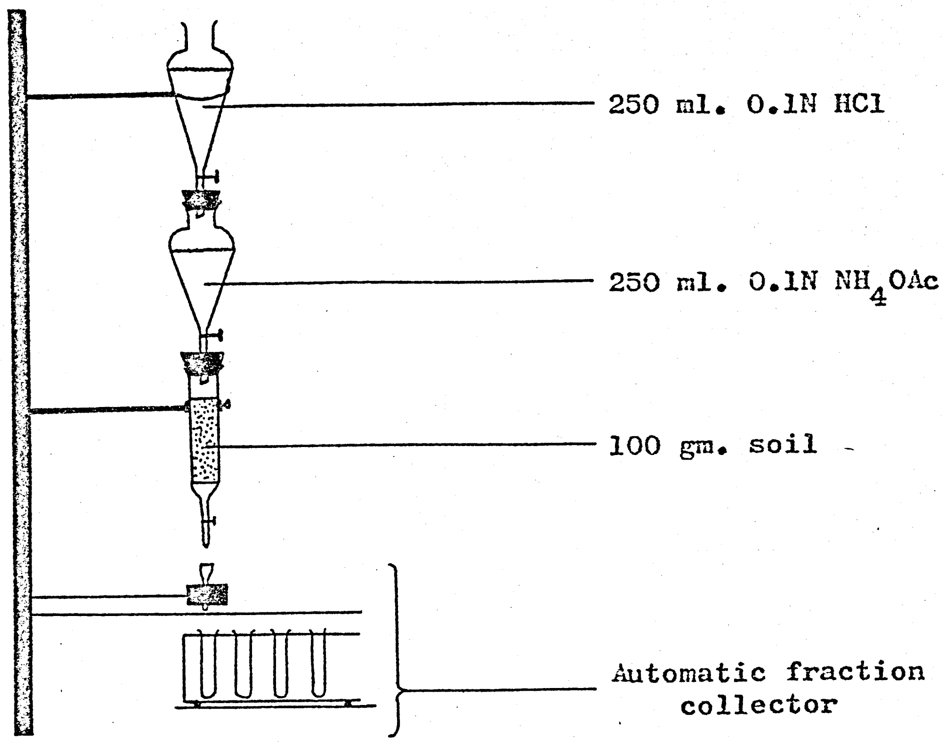

Figure 1. Soil leaching apparatus.

the Walkly-Black method (Jackson, 1958). This sequence was repeated until the effluent was exhausted. Approximately 180 ml. of effluent gave seven samples for emission spectrograph analysis and four samples each for titration and organic matter determination. Fractions were taken in order of their collection, the first effluent to be collected giving sample number one, and the last sample number seven or four.

DISCUSSION

The pH determination showed values of 5.7 for unburned soil and 6.2 for burned soil. Thus acidity was decreased by burning. Percent total nitrogen increased as a result of the fire. Unburned soil had 0.100 percent total nitrogen, while burned soil had 0.126 percent. Knight's findings (1966) indicate, however, that while the concentration of total nitrogen in the residual matter may have increased, there may well have been a net loss of nitrogen from the ecosystem as a whole. The question remains as to the effect of these changes upon vegetative growth. Titration failed to indicate a hydrogen ion concentration gradient. Values of 0.03 normal were obtained in each case. The patterns, as leaching progressed, of organic matter and nutrient release indicate, however, that a gradient did exist but that the ammonium acetate had a greater buffering capacity than expected. This would effectively mask the gradient.

The organic matter in 5 ml. fractions of effluent is presented in Table 1. In both soils, organic matter increased as leach-

Fraction (5 ml.)	Organic Matter (micrograms)	
	No Burn	Burn
1	80	155
2	120	185
3	185	232.5
4	232.5	232.5
Total	617.5	805.5

Table 1. Organic matter content of effluent from burned and unburned soil.

ing progressed indicating that the leaching solution was becoming more acid. Thirty one percent more organic matter was removed in 20 ml. of effluent from burned soil compared to effluent from unburned soil.

The amounts of four plant macronutrients, five plant micronutrients, and strontium in 20 ml. fractions are presented in Appendix A. Table 2 presents the total amount of each element removed in 140 ml. of effluent from each soil. The percent increase (decrease) of burned soil over unburned soil is also indicated. Manganese is not included in Table 2 as some of the fractions contained more of this element than the machine was calibrated to read.

Element	Total Amount* (in 140 ml.)		Percent Increase (decrease)
	No Burn	Burn	
Phosphorus	260	680	162
Potassium	6760	9260	37
Calcium	31720	39660	25
Strontium	96.266	152.298	58
Iron	81.142	101.566	25
Magnesium	7080	6940	(2)
Zinc	41.456	47.954	16
Molybdenum	1.986	1.732	(13)
Boron	20.436	17.712	(13)

* in micrograms

Table 2. Total amounts and percent increase (decrease) of elements in 140 ml. of effluent from burned and unburned soil.

Interesting relationships exist between the two soils. Among the macronutrients, phosphorus, calcium, and potassium were substantially increased while magnesium was only very slightly decreased. The micronutrients iron, manganese, and zinc, as well as strontium were present in larger quantities in the burned soil. This would seem to indicate that these elements are tied up in rather large amounts in organic matter. Among the micronutrients, only molybdenum and boron were decreased by burning. The total amount of these two elements were the smallest of any tested, and the decreases indicated were small. It is questionable if any significance could be placed on them.

All of the elements (except potassium) show a tendancy to have high concentrations in early fractions, tapering to a low in later fractions, and then increasing in the last. The late increases are undoubtedly related to the increase in organic matter. Also, the patterns of both element and organic matter release indicate a hydrogen ion gradient existed as mentioned earlier. The availability of most plant nutrients is dependent upon Ph (see diagram) in Buckman and Brady, 1965 p. 370). Furthermore, organic matter becomes more soluble as acidity increases. The patterns noted indicate that the leaching solution probably started out quite alkaline and became more acid. It can be possible that the final pH was in the 5.5 to 6.5 range (where nutrients are generally most available), but this is speculation.

Potassium, unlike the other elements tested, tended to be rapidly leached from both soils as is evidenced by the steady decrease in its quantities in the fractions. Potassium is generally considered to be one of the most mobile nutrients in soil and is not bound in large quantities by organic matter.

CONCLUSION

Burning appears to increase the availability of most of the plant nutrients (with the exception of magnesium, molybdenum, and boron) tested. Increases ranging from 16 to 162 percent were noted. Organic matter was shown to increase (31 percent) and, as a result of the increase in available bases, pH increased from 5.7 to 6.2.

It must be remembered, however, that fire increases only the availability of nutrients. It does not increase the total amounts of nutrients in an ecosystem (as fertilization would) and may even result in a net loss of certain elements (nitrogen ?). Furthermore, the benefit of fire depends upon a number of factors. Fire on an area with hilly topography may be detrimental. Rain or snow-melt runoff may, in these situations, remove the more readily available nutrients and a nutrient deficient rather than enriched situation might result. The bulk of nutrients released by most fires comes from the breakdown of organic soil horizons. Litter layers act as buffers concentrating nutrients brought up from the subsoil and deposited on the surface by vegetation. Decomposition of the litter results in a recycling of nutrients to the mineral soil where they can again be utilized by plants. Fire accelerates this process, but its benefits (if any) are not well understood. The ability of plants to respond to the changes reported will be the subject of further research involving the soils described here.

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APPENDIX

Total amounts (in micrograms) of elements in 20 ml. fractions of effluent

Fraction	Phosphorus No Burn	Phosphorus Burn	Potassium No Burn	Potassium Burn	Calcium No Burn	Calcium Burn	Strontium No Burn	Strontium Burn
1	70	100	2340	2640	9280	7920	29.546	31.568
2	50	100	1760	1920	6660	6200	20.050	21.834
3	30	80	1060	1440	4080	5420	11.020	20.192
4	30	60	600	1120	2800	4140	7.866	14.086
5	20	60	360	880	2120	3440	6.432	12.166
6	20	80	320	660	2240	4380	6.748	16.858
7	40	200	320	600	4540	8160	14.604	35.594

Fraction	Iron No Burn	Iron Burn	Magnesium No Burn	Magnesium Burn	Zinc No Burn	Zinc Burn	Molybdenum No Burn	Molybdenum Burn
1	14.486	16.884	2900	1800	5.968	3.852	0.642	0.364
2	19.282	12.942	1720	1340	5.768	9.710	0.400	0.326
3	14.142	12.086	840	1060	4.286	4.922	0.270	0.270
4	7.966	15.172	500	800	17.846	6.830	0.202	0.174
5	6.422	12.600	320	580	2.616	4.824	0.116	0.154
6	4.530	17.740	320	620	*	7.240	0.154	0.184
7	14.314	14.142	480	740	4.972	10.576	0.202	0.260

Fraction	Manganese No Burn	Manganese Burn	Boron No Burn	Boron Burn
1	**	**	6.956	3.024
2	91.588	94.320	4.556	4.362
3	55.674	86.988	1.392	1.814
4	37.866	66.926	1.504	1.618
5	28.730	56.772	0.966	1.618
6	33.078	85.574	2.238	3.332
7	92.708	**	2.828	4.944

*= $<$ 2
**= $>$ 104